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REVIEW

Campylobacteriosis: the role of poultry meat

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Abstract

The incidence of human infections caused by *Campylobacter jejuni* and *Campylobacter coli*, the main bacterial agents of gastrointestinal disease, has been increasing worldwide. Here, we review the role of poultry as a source and reservoir for *Campylobacter*. Contamination and subsequent colonization of broiler flocks at the farm level often lead to transmission of *Campylobacter* along the poultry production chain and contamination of poultry meat at retail. Yet *Campylobacter* prevalence in poultry, as well as the contamination level of poultry products, vary greatly between different countries so there are differences in the intervention strategies that need to be applied. Temporal patterns in poultry do not always coincide with those found in human infections. Studies in rural and urban areas have revealed differences in *Campylobacter* infections attributed to poultry, as poultry seems to be the predominant reservoir in urban, but not necessarily in rural, settings. Furthermore, foreign travel is considered a major risk factor in acquiring the disease, especially for individuals living in the northern European countries. Intervention strategies aimed at reducing *Campylobacter* colonization in poultry and focused at the farm level have been successful in reducing the number of *Campylobacter* cases in several countries. Increasing farm biosecurity and education of consumers are likely to limit the risk of infection. Overall, poultry is an important reservoir and source of human campylobacteriosis, although the contribution of other sources, reservoirs and transmission warrants more research.

Keywords: Antimicrobial resistance, *Campylobacter*, *Campylobacter coli*, *Campylobacter jejuni*, infection, intervention measures, molecular epidemiology, poultry, transmission
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Campylobacter infections

Of the 25 *Campylobacter* species validly described to date (http://www.bacterio.net/campylobacter.html, last accessed 21 August 2015), *Campylobacter jejuni* and *Campylobacter coli* are the two predominant species causing gastrointestinal infections. However, other species such as *Campylobacter lari*, *Campylobacter upsaliensis* and *Campylobacter concisus* have also been associated with gastrointestinal disease in humans. In this review, *C. jejuni* and *C. coli* will be referred to as *Campylobacter*, unless otherwise stated.

Human campylobacteriosis typically develops 1–5 days after exposure and is characterized by watery and sometimes bloody diarrhoea, fever, abdominal cramps and vomiting lasting for approximately 5–7 days. Campylobacteriosis is the most common infection preceding the onset of post-infectious Guillain–Barré syndrome, a severe demyelinating neuropathy, occurring in approximately 3/10 000 campylobacteriosis cases [1]. Furthermore, other sequelae, such as reactive arthritis and irritable bowel syndrome, significantly add to the burden of disease [2]. Campylobacteriosis is usually self-limiting and antimicrobial treatment is often not required, except in severe cases or patients with a compromised immune status.

Several studies have estimated the burden of campylobacteriosis, expressed as disability-adjusted life-years (DALYs). Recent estimates range from 1 568 DALYs in New Zealand [3], 3 633 in The Netherlands [2] up to 18 222 in Australia [4] and 22 500 in the USA [1]. The major driver of DALYs for

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TABLE 1. Campylobacteriosis worldwide

Continent / country	Notification rate/100 000	Year	Reference
Europe			
Austria	67.7	2013	[6]
Denmark	67.3	2013	[6]
Estonia	28.9	2013	[6]
Finland	74.9	2013	[6]
Germany	77.3	2013	[6]
Iceland	31.4	2013	[6]
Lithuania	38.3	2013	[6]
Norway	65.2	2013	[6]
Slovenia	49.9	2013	[6]
Sweden	84.9	2013	[6]
United Kingdom	104	2013	[6]
North America			
Canada	29.3	2012	[a]
USA	13.5	2014	[b]
Oceania			
Australia	112.3	2010	[c]
New Zealand	152.9	2013	[d]

[a]Public Health Agency of Canada (http://dsol-smed.phac-aspc.gc.ca/dsol-smed/ndis/charts.php?c=pl, last accessed 22 July 2015).
[b]Campylobacteriosis rate in 2014 in the USA, http://www.cdc.gov/foodnet/index.html, last accessed 22 July 2015.
[c]http://www.health.gov.au/internet/main/publishing.nsf/content/cda-cdi3601-pdf-cnt.htm/$FILE/cdi3601a.pdf, last accessed 22 July 2015.
[d]http://www.foodsafety.govt.nz/elibrary/industry/FBI-report-2013.pdf, last accessed 28 July 2015.

Campylobacter has been the number of years lost due to disability caused by sequelae of the infections [1,4]. *Campylobacter* are a leading cause of bacterial enteritis in Europe [5] and campylobacteriosis is also one of the most expensive foodborne diseases in Europe and Oceania [2,3].

Table 1 gives an overview of the number of reported *Campylobacter* cases worldwide. Many countries have a mandatory *Campylobacter* notification system and increasing notification rates of the disease have been shown [6]. For example, in the European Union (EU) in 2009, 201 711 *Campylobacter* cases were reported, and this number increased to 214 779 in 2013 [6]. In the USA, an increase of 13% was shown in cases reported in 2014, compared with the figures from the period 2006–2008 (http://www.cdc.gov/foodnet/index.html, last accessed 28 July 2015).

Generally, *Campylobacter* infections peak in certain age groups; young children (<4 years of age), young adults (20–40 years of age) and the elderly (>75 years of age) [7,8], which may be due to different risk factors in certain age groups [7,9,10]. Reports from regions other than Europe and North America are still scarce, and often show an overall low detection rate from human samples.

Chicken food chain and *Campylobacter*

Poultry encompasses chicken, turkey, duck and laying hens, of which chicken (*Gallus gallus*) is the predominant species used for meat production (70%–80%). Global poultry meat production has increased from 58.5 million tonnes in 2000 to 95.5 million tonnes in 2014 (http://www.thepoultrysite.com/focus/global-poultry-trends/2400/global-poultry-trends-region-select-track-poultry-trends-across-the-world, last accessed 25 August 2015). Production is not equally distributed; the Americas accounted for 43% of the total production, Asia (mainly China) for 34%, Europe for 17% and Africa and Oceania for 5% and 1% of the whole production in 2012 (93 million tonnes), respectively. In 2023, poultry meat is expected to be the largest meat sector by around 130.7 million tonnes (OECD (2015), Meat consumption, http://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook_19991142, last accessed 31 August 2015). Although free-range and organic poultry productions are also increasing in industrialized countries, their quantities are still minor and beyond the scope of this review.

An Expert Opinion Assessment by the European Food Safety Authority has estimated that chicken meat consumption accounts for 20%–30% of campylobacteriosis in the EU, whereas 50%–80% may be attributed to the chicken reservoir as a whole, stressing that broiler meat production accounts for variable numbers of campylobacteriosis cases in different countries [11]. This also means that the approximate doubling of the chicken meat production from 58.5 million tonnes in 2000 to 95.5 million tonnes in 2014 has clearly affected the global burden of campylobacteriosis and the continuing growth of poultry meat production will put further pressure on the poultry industry and public health authorities to reduce poultry/chicken-associated human *Campylobacter* infections.

The stages in the chicken meat production and processing chain consist of primary production at rearing farms, transport to slaughter, the slaughter process and subsequent processing of chicken meat products, selling products at the retail level, and handling and consumption of chicken meat products at home and in public places such as restaurants. All of these stages have a role in the transmission of *Campylobacter* from farm to fork. Production chain conditions vary between countries, and this is also reflected in the annual number of *Campylobacter*-positive chicken flocks. In the EU, the variation in *Campylobacter* prevalence has been from 0.6% to 13.1% in the Nordic countries Finland, Norway and Sweden, up to 74.2%–80% in several other countries [6]. Moreover, *Campylobacter* prevalence on farms subsequently reflects the presence of *Campylobacter* found on carcasses and meat (Table 2).

The most important factors for slaughter batches to become *Campylobacter* positive have been shown to be partial depopulation of the flock (thinning), slaughter in the summer (June, July and August), increasing bird age at slaughter (from 36 days to >40 days), common health status of the flock (measured as mortality) and increasing number of rearing houses at the farm [12,13]. This indicates that the major contamination site in the

chicken meat production is at the rearing farm [11–13]. Vertical transmission from parent to young chicks is uncommon and a flock is usually identified as *Campylobacter* positive at the age of approximately 2 weeks. Flocks at commercial production systems consist of approximately 10 000–30 000 birds per house, with several houses present at a farm, potentially facilitating high levels of *Campylobacter* amplification and rapid spread within the flock. A flock is either colonized by one strain only or, at farms with less stringent biosecurity, multiple strains can colonize the same flock simultaneously [14]. Transport has only a limited effect on the contamination of carcasses, whereas during the slaughter process, plucking and evisceration lead to contamination of carcasses. At the end of the processing line, various types of products are on sale in different countries, starting from fresh or frozen whole carcasses to pieces of cuts and portions; this accounts for the divergent quantities of infection risk. Generally, skinless portions such as breast fillets and slices contain lower *Campylobacter* counts than portions with skin [11].

Epidemiology

The great majority of *Campylobacter* infections are sporadic, and a wide variety of animal species can carry the organisms in high numbers and act as a reservoir, which complicates tracing and attribution of the original source of infection. Human exposure can come through direct contact with animals, food (e.g. raw or undercooked meat and unpasteurized milk) or environmental reservoirs (e.g. natural bodies of water) [15]. Pulsed-field gel electrophoresis, multilocus sequence typing (MLST) and *fla*-typing have all been methods commonly used to study the distribution of different genotypes in various reservoirs and sources [16–18]. As a result of the weakly clonal population structure, especially of *C. jejuni*, MLST based on sequencing of seven housekeeping genes has been particularly suitable to study the long-term changes in sequence type (ST) distribution at both local and global levels [18–20]. Subsequently, mathematical models using MLST data have been employed to assign patient isolates to potential sources. In studies employing MLST and mathematical modelling, it has been found that chicken are the most common reservoir/source of *Campylobacter* infection, with attributions varying from 38% to 77%, whereas cattle have been named as the second most common source, with attribution rates varying between 16% and 54% (Table 3). Generally, source attribution studies have greatly improved our understanding of the relative contributions by different sources to human infection. However, the assignment of one source to one genotype by the source attribution model may subsequently result in over-attribution of particular sources to human infections. This has been particularly seen for generalist genotypes, such as ST21 and ST45, which are commonly found from a large number of sources and reservoirs, but often bovines or chickens are assigned as their sources [7,21,22]. This issue can partially be resolved by studying the allelic variation at genome level in a whole genome MLST approach, which allows for a more refined way to resolve the association of possibly epidemiologically linked isolates [23–25]. In addition, when MLST data are only available for a limited number of potential sources apart from poultry, this can lead to over-estimation of the role of poultry. Ultimately, epidemiological studies using case–control data combined with robust typing of the isolates improve sensitivity of the source attribution [22].

Seasonal peaks in human *Campylobacter* cases, mostly in July–August, are commonly observed in western countries with temperate climates [6,26–28], whereas this is less marked

TABLE 2. Prevalence of *Campylobacter* in European poultry meat at retail

Country	Study period	Type of sample	Prevalence	Species[a]	Reference
Austria	2013	Broiler meat	71%	ND	[6]
Denmark	2013	Broiler meat	12%	ND	[6]
Finland	2013	Broiler meat	11%	ND	[6]
France	2009	Broiler meat	76%	*Cj*: 65% *Cc*: 35%	[48]
Germany	2013	Broiler meat	38%	ND	[6]
The Netherlands	2013	Broiler meat	32%	ND	[6]
Hungary	2013	Broiler meat	24%	ND	[6]
Poland	2009–2013	Chicken meat Turkey meat	50% 41%	*Cj*: 40% *Cc*: 37% *Cj*: 31% *Cc*: 69%	[49]
Slovakia	2013	Broiler meat	36%	ND	[6]
Slovenia	2013	Broiler meat	54%	ND	[6]
Spain	2013	Broiler meat	70%	ND	[6]
Turkey	2009–2010	Chicken meat	56%	*Cj*: 42% *Cc*: 14%	[31]

[a]Cc, *Campylobacter coli*; Cj, *Campylobacter jejuni*; ND, not discriminated.

TABLE 3. Comprehensive overview of *Campylobacter* source attribution studies published between 2010 and 2015

Country	Study period	Source attribution	Reference
Canada	2005–2007	Chicken: 64.5% Cattle: 25.8% Water: 8.4% Wild birds: 2.3%	[7]
Denmark	2007–2008	Domestic chicken: 54%/38%[a] Imported chicken: 17%/14%[a] Cattle: 17%/16%[a]	[50]
The Netherlands	Combined periods 2000–2007 and 2010–2011	Chicken: 68% Cattle: 24% Environment: 6% Sheep + pig: 2%	[19]
The Netherlands[b]	2002–2003	Chicken: 66.2% Cattle: 20.7% Environment: 10.1% Sheep: 2.5% Pigs: 0.3%	[22]
Scotland	2005–2006	Poultry: 46.3% Ruminant: 31.0% Wild bird: 1.9%	[36]
Scotland[c]	2005–2006	Ruminants: 54% Chicken: 40% Pigs: 6%	[9]
Switzerland	2002–2012	Chicken: 70.9% Cattle: 19.3% Dogs: 8.6% Pigs: 1.2%	[18]

[a]The first percentage indicates source attribution determined by the asymmetric island model. The second percentage indicates source attribution by the *Campylobacter* source attribution model developed by the authors.
[b]Animal data supplemented with data from UK, Scotland, Switzerland, New Zealand, Curaçao, Finland and USA.
[c]Only *C. coli* included.

in Australia, New Zealand and countries with tropical climates [27–30]. In line with the summer peak in human infections, higher isolation rates of *Campylobacter* from chickens in summertime, compared with the winter season, have been observed [14,31,32]. However, the human infection peak often precedes the prevalence peak of chicken slaughter batches, suggesting that both may have acquired *Campylobacter* from the same source [11,32,33]. Furthermore, MLST typing has shown that the same sequence types (ST45, ST230 and ST677) occur during the summer peak in both human patients and chickens, which raises the question of common environmental sources for these types [34,35]. Although the reasons for *Campylobacter* seasonality are not well understood, increase in potential reservoirs, human behaviour and climate may all play a role in the shedding and subsequent transmission of the bacteria. Furthermore, variation in the risk of acquiring campylobacteriosis between rural and urban regions has been documented [7,29,36,37]. These studies suggest that chicken may play a more prominent role in the transmission of *Campylobacter* to humans residing in urban regions, whereas ruminant-associated genotypes have often been more commonly detected from people living in rural areas [7,29,36,37].

Despite the recognition of poultry as a substantial source and reservoir for *Campylobacter* more risk factors have been described. A substantial proportion of human *Campylobacter* infections are travel-related and the genotypes from travel-associated isolates are often divergent compared with domestically acquired *Campylobacter* isolates [28,38,39]. In a Swiss risk analysis study, the highest risk for travel-related *Campylobacter* infection was among persons aged 20–59 years [10]. In other risk analysis studies, Swedish residents travelling to other EU countries had a risk of acquiring campylobacteriosis of 15.9 per 100 000 journeys abroad [40] and Dutch residents travelling to Asia, Africa, Latin America, the Caribbean and southern Europe had a higher risk of acquiring campylobacteriosis when compared with residents travelling to northern and eastern Europe and Oceania [38].

Workers at poultry abattoirs are an interesting group in which to study the effect of occupational exposure to potentially contaminated poultry on *Campylobacter* infection. Recently, two studies, one conducted in Sweden [41] and the other conducted in the USA [42], showed divergent results on campylobacteriosis in poultry abattoir workers. In the US-based study, the great majority (83%) of the symptomatic workers with laboratory-verified *Campylobacter* infection had been working at the slaughterhouse for less than a month [42]. In the Swedish prospective study, workers who became stool culture positive for *Campylobacter* did not exhibit symptoms, although more than half (57%) had been employed for less than a year [41]. Both studies included a small number of workers and it will be of great interest to have more studies conducted on the role of occupational exposure to better understand protective immunity in humans and virulence of poultry-associated *Campylobacter*.

Antimicrobial resistance

Fluoroquinolones, such as ciprofloxacin, and macrolides, such as erythromycin, have been the primary antimicrobials used for the treatment of human *Campylobacter* infections. Resistance to fluoroquinolones requires only one point mutation in the *gyrA* gene and resistance has increased rapidly among chicken and human *Campylobacter* isolates since the early 1990s [43]. Studies have shown a clear positive association between the use of fluoroquinolones in poultry production and increased resistance among chicken and human *Campylobacter* isolates [43–45], whereas in countries not permitting the use of fluoroquinolones in poultry production, such as Australia and the Nordic European countries, few resistant *Campylobacter* isolates are found from chickens and humans with domestically acquired infections [44]. The USA banned the use of the fluoroquinolone enrofloxacin in chickens in 2005. Despite this, resistance to ciprofloxacin in *C. jejuni* from chicken slaughter batches has remained stable at 22% between 2005 and 2013,

although at retail level, ciprofloxacin resistance decreased from 17% in 2005 to 11% in 2013. Moreover, ciprofloxacin resistance in human *C. jejuni* isolates in 2013 remained at the same level as in 2005 (22%) (http://www.fda.gov/downloads/AnimalVeterinary/SafetyHealth/AntimicrobialResistance/NationalAntimicrobialResistanceMonitoringSystem/UCM453398.pdf, last accessed 23 September 2015). The reasons for persistence of resistance are not well understood.

In the EU member states, in 2013, ciprofloxacin resistance among human *Campylobacter* isolates ranged from 23% in Denmark to 92% in Spain [45]. Resistance to ciprofloxacin can also be related to foreign travel, especially to Asia; in 2013 it was shown that 90% of the tested isolates originating from Asia were resistant [45]. Ciprofloxacin resistance among isolates from broilers at slaughter ranged from 0% in Finland to 90% in Spain [45]. Tetracycline resistance showed similar trends as ciprofloxacin in the EU member states, whereas resistance to macrolides, currently considered the drugs of choice for treatment of human *Campylobacter* infections, was low, which is probably because of their limited use in poultry production [45]. Multidrug resistance has been uncommon in *Campylobacter* derived from both humans and poultry [45].

Intervention measures

Reduction of *Campylobacter*-positive chicken flocks, thereby decreasing prevalence and bacterial counts on meat, is the most relevant strategy to reduce the number of human *Campylobacter* infections. Because the farm is the preliminary site of *Campylobacter* entry into the production, the major intervention strategies should be targeted at farm level. First-line intervention is to improve the biosecurity (hygiene barriers and restricted access), which prevents *Campylobacter* transfer from the outside environment into rearing houses. This requires increased education of farmers and awareness of management and biosecurity procedures and how to improve these. Other intervention measures deal with abandoning thinning of flocks during the rearing period, because this procedure increases the transfer of *Campylobacter* into the flock [11]. Also, fly screens combined with other adequate biosecurity measures have been shown to decrease the number of positive batches in Denmark [33].

The interventions at slaughter process are less efficient; decreasing *Campylobacter* counts on products by 1 log unit has been estimated to decrease human risk by 50%–90% [11]. Proper hygiene during slaughter and proper washing and chilling of carcasses decrease the numbers of *Campylobacter* on carcasses [11]. The European Food Safety Authority BIOHAZ Panel has estimated that a public health risk reduction of 50%–90% could be achieved if all batches complied with microbiological criteria with a critical limit of <1000 and <500 CFU/g of neck and breast skin, respectively [11]. Furthermore, the frequency of contaminated carcass samples varied among the different European countries and there was a trend for higher quantitative loads of *Campylobacter* on carcasses in countries with higher *Campylobacter* prevalence in both slaughter batches and carcasses [11]. These results indicate that the interventions needed to reduce human health risks are not the same in different countries.

Chemical decontamination of carcasses with, for example, chlorine, chlorine dioxide, tri-sodium phosphate and lactic acid, may be used to decrease the number of *Campylobacter* on carcasses, but none of these treatments are allowed in the EU [11]. In addition, freezing chicken meat has been successful in reducing *Campylobacter* counts [11]. At retail level, selling the meat prepacked and marinated as ready-to-oven products may also decrease the consumer risk during food preparation at home [46]. The final consumer risks can be reduced by preventing cross-contamination of ready-to-eat foods from cutting boards, knives and hands during food preparation as well as heating foods at temperatures that kill the organisms. However, this requires increased consumer awareness; in a recent survey by the Food Standards Agency in the UK, only 28% of the people had heard of *Campylobacter*, compared with 90% who had heard of *Escherichia coli* and *Salmonella* (http://www.food.gov.uk/news-updates/news/2014/6084/fsw).

The list of potential measures to decrease poultry-associated *Campylobacter* risk allows for selection and combination of the best methods fitting to local conditions. In New Zealand, a country with a high incidence of campylobacteriosis, interventions at different levels in the primary poultry production have been effective in reducing the number of *Campylobacter* infections [47]. In the EU, the BIOHAZ panel has presented a detailed description of options on potential intervention possibilities and estimations of their effects on human *Campylobacter* infections in different EU member states [11], but implementation has not yet been very efficient because of the reluctance to make the necessary economic investments and the general attitude towards the long-term management of poultry production.

Conclusions

Human *Campylobacter* infections have been increasing in the past decade and poultry has been identified as the major contributor. It is evident that the majority of infections can be attributed to poultry, yet these attributions differ between countries and even for sparsely and highly populated areas

within a country. Peaks in human infections often precede peaks in chicken, suggesting that other sources could supply *Campylobacter* to both humans and chickens and that chickens often act as a reservoir.

Colonization of poultry occurs at the farm level where it is necessary to focus on enhancing the biosecurity and implement monitoring. Intervention strategies and monitoring programmes in the primary poultry production chain have been established, and shown to be successful in decreasing the colonization rate of broilers in several northern European countries and New Zealand.

Finally, in countries with a low colonization rate of chicken flocks, such as Finland, Norway and Sweden, sources other than chickens may play a larger role, especially for domestically acquired infections. Travel-associated infections are an important factor to consider and together with the changing global food markets, such as increasing consumption of imported chicken, these will affect *Campylobacter* infections worldwide.

Transparency declaration

The authors declare that they have no conflicts of interest.

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